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Notes on the Coast of the United States

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LECTURE

ON THE

GULF STREAM,

Prepared at the request of the American Association for the Advancement of Science.

BY A. D. BACHE,
Supt. U. S. Coast Survey.*

[Delivered before the American Association for the Advancement of Science, at Newport.]

BY request of the Association, at their last meeting, at Springfield, I now present a summary of the results of the Gulf Stream explorations made by the officers of the Coast Survey.

The Gulf Stream is the great hydrographic feature of the United States coast, and no survey of the coast could be complete for purposes of navigation, without it. Hence the explorations have been early undertaken and thoroughly carried on. But as it required peculiar means and special adaptation in the officers to this line of research, and did not require a continuous survey, the work has been executed from time to time, as means and officers could be had without interference with the more regular operations of the hydrography.

An act of Congress which refers to this Survey, requires the immediate presentation of its results to Congress and they have therefore been discussed as soon as procured and have been given to the public.

This is the great sea mark of the coast of the United States, both Gulf and Atlantic, and its qualities as hindrances and aids to navigation require that the navigator should be well informed in regard to it.

* Communicated by the Author.

In order to present an intelligible summary of the results obtained by the Coast Survey in the short time allowed for a lecture, it is necessary to condense the subject very considerably, to omit matters at all extraneous to the subjects in hand, and to confine myself to a brief and direct statement of *the means employed in examining the stream from its surface to its depths, the method of studying the results*, and *of the results themselves*.

The temperatures in and near the Gulf Stream, are among its most striking peculiarities, and therefore have formed one principal object of observation. It will be necessary in order to bring the subject within limits, to confine myself chiefly at this time to the consideration of this class of facts and to the results and laws connected with them.

I shall proceed therefore to consider the subject under the following heads:

1. The Instruments for determining depths and temperatures and for obtaining specimens of the bottom.
2. The plan of research.
3. The method of discussion of the results.
4. The results, consisting of type-curves of the law of change of temperature with depth, at several characteristic positions. Type-curves showing the distribution of temperatures across the stream, represented by two sets of curves, one in which the variable temperatures at the same depth is shown, and the other in which the variable depth of the same temperature is represented. Upon the diagrams showing these latter curves, the figure of the bottom of the sea is given, where it has been obtained.

Discussion in regard to the cold wall, which is one of the most interesting features of the approach to the Gulf Stream.

5. The limit of accuracy of the results.
6. The figure of the bottom of the ocean below the Gulf Stream.
7. The general features of the Gulf Stream as to temperature.

These points are illustrated by diagrams, enabling the eye to follow the results as they are stated.

I. Instruments.

1. *For Temperatures.*—The instrument for determining temperatures should fulfill the two conditions of registering its indications and of being unaffected by pressure. The common mercurial thermometer, while it answers perfectly for the determination of temperatures at the surface, fails in both the conditions stated. The ordinary self-registering thermometer, or self-registering metallic thermometer, in the watch form, as made by Breguet, Montandon, and Jürgensen, when provided with a suitable cover to protect it from pressure, answers a good purpose, and has been extensively applied in the course of the observations. As

a rule it is only the minimum temperature thermometers that must be used, as the temperatures decrease generally in descending. An ordinary self-registering minimum thermometer placed in a glass globe, was successfully used by Commander Charles H. Davis, and by Lieut. G. M. Bache. It has the disadvantage of taking the temperature slowly, and of being inapplicable below a certain depth. Small hollow cylindrical brass vessels which were divided in two parts closely fitted by grinding, and within which the Breguet thermometers of the watch form were placed, were an improvement upon the glass globe, as taking the temperature of the sea more rapidly, but besides the difficulty of making the joint tight, they were crushed by the pressure, at even moderate depths. The substitution of a globe, for the cylinder, extended the range of these instruments, but the thermometers were often crushed or injured by the access of sea-water to the interior of the globe. Six's self-registering thermometers as bearing considerable pressure without injury and without rendering the indications erroneous, and as requiring no case to enclose them, except to prevent breaking from accidental knocks in handling, are very useful. They are still favorites with many of the officers, though others complain of their great liability to derangement, especially if the mercury is not perfectly clean, when the mercurial column easily separates and some skill is required to bring it together. These instruments are from their cheapness still furnished to the parties and are used successfully at depths reaching about one hundred fathoms, and on occasions, considerably lower. Keeping them in order requires the skill of an experimenter, rather than that of an observer, and hence they do not satisfactorily fulfill the conditions of the problem. The metallic thermometer of Joseph Saxton, Esq., of the U. S. Office of Weights and Measures, is a compound coil resembling somewhat the well known instrument of Breguet. In its construction, two stout ribbons, of silver and platinum—carefully united by silver solder to an intermediate thin plate of gold—are coiled with the more expansible metal in the interior. The gold serves to prevent the tendency of the silver and platinum to separate. The lower end of this coil is fastened to a brass stem passing through the axis of the coil, while its upper end is firmly attached to the base of a short cylinder. The whole motion of the coil as it winds and unwinds with variations of temperature, thus acts to rotate the axial stem. This motion is magnified by multiplying wheels contained in the short cylinder at top, and is registered upon the dial of the instrument by an index, which pushes before it a registering hand, moving with sufficient friction merely to retain its place when thrust forward by the index hand of the thermometer. These instruments are

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graduated by trial. The brass and silver portions receive a thick coating of gold by the electrotype process to prevent the action of the sea-water upon them.

When kept clean by frequent washing in fresh water, and in good order and frequently compared with the standards to guard against accidental derangements, these thermometers answer admirably all the required conditions. The length of the coil measured along its axis should not be less than six inches, as the interposition of wheels to magnify the motion, should as far as possible, be avoided. The water being all around the coil, which is a good conductor, and has a low specific heat, the instrument readily feels the temperature of the part of the sea where it is exposed, and registers it to less than half a degree (say 0·2) with certainty. The box which covers the coil and indicating part of the thermometer is merely to protect it from accidental injury, and is open so as to permit the sea-water to pass freely through it. Plate IV gives a view of Saxton's metallic thermometer, and of its various parts in detail. Although there seemed no reason to doubt that this instrument was free from any effects of pressure, it was deemed desirable to actually try it by extreme pressure and a series of experiments made by J. M. Batchelder, Esq., showed that at pressures less than that corresponding to 600 fathoms, the effect was less than one degree (0°·25 to 1°) and at pressures from 600 to 1500 fathoms the change amounted to little more than from 7° to 9° Fahr., the index returning when the pressure was removed. For great depths the effects of pressure must be ascertained, as it is specific in each instrument and probably depends chiefly upon some mechanical defect in the construction, perhaps in the soldering.*

The apparatus used in these experiments on the effect of pressure, was a very ingenious one for testing hydraulic engines by Mr. Thomas Davison of the Novelty Iron Works of New York. Fig. No. 12, Plate IV.

2. *For Depths.*—Where the depth becomes considerable the usual sounding line fails entirely to give it, especially if there is a current and more especially if there is besides, a counter-current. The amount of "stray line" is very variable. This subject has been ably examined of late years by Commanders Maury and S. P. Lee, Lieuts. Berryman, Brooke and others of our navy, and by Commander Dayman and others of the British navy, and especially by Prof. Trowbridge of the Coast Survey in his memoir read before the Association ("Deep Sea Soundings," by W. P. Trowbridge, Assistant U. S. Coast Survey,) at the meeting in Baltimore and re-published in the American Journal of Science and Arts, vol. xxviii for the year 1858.

* Gulf Stream Explorations; Third Memoir Proceedings Amer. Assoc. Adv. Sc., 18th Meeting, Springfield, 1859, and this Jour., [2], vol. xxix, 1860.

The use of Ogden's or Ericcson's leads to 100 fathoms is still continued by some of the officers of the survey, though, at such depths, nothing better than the common sounding line is in fact required. Massey's lead with Woltman's wheel, as an indicator. has been extensively used of late years. Mr. Saxton's indicator is more simple than Massey's, but acts upon the same principle. To remedy the defect of the turning of the cord of the lead line, two indicators are applied, one on each side of the axis. Prof. Trowbridge's leád modified somewhat from that described at the last meeting of the Association in Baltimore, has recently been tried with good success by Lieut. Comdg. Wilkinson in the last soundings across the Straits of Florida for the telegraph to Havana. The most reliable observations heretofore made in the Coast Survey have been with Massey's indicator; the errors are not such as to affect the development of the laws of change at the moderate depth reached in most of the observations, and at great depths the changes are very slow. The new apparatus has the advantage of saving a great deal of time and therefore inaccuracies from change of position during the sounding are avoided.

3. *For obtaining specimens from the bottom.*—The only satisfactory test of having reached the bottom of the sea at considerable depths being the bringing up of a specimen, this has been a subject of constant study with us. The different instruments invented by Lieut. Stellwagen, Commander Sands, Lieut. Craven, Lieut. Berryman, Lieut. Brooke and other officers of our navy, are all in use for different kinds of bottom, and according to the preference given by different hydrographic chiefs. The one most commonly used in these explorations has been Lieut. Stellwagen's invention; a cup placed below the sounding lead, covered by a dick or valve of leather which slides up the stem of the cup and opens when the lead is descending, closing when it is raised. The weight of the lead and the turning of the cord generally suffice to sink the cup into the bottom, filling it, and when the valve is made to close tightly by a piece of flexible leather below the stiff disk, the specimen is not washed out as the lead is drawn up. In Commander Sands' sounding apparatus a spring keeps an outer cylinder over an opening in an inner hollow one, until it reaches the bottom, when the outer cylinder is forced upwards and the opening at the side of the inner one, which, having a conical termination, penetrates the bottom, permitting a specimen of the bottom to pass in. On raising the lead the spring forces the outer cylinder over the opening, preventing the specimen from being washed out. The only very deep soundings being, as a general rule, in soft bottom, Sands' specimen-cylinder is admirably adapted to that class of work.

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II. Plan of the Work.

The plan of the work was simple. The temperatures were to be ascertained at various depths, at different distances from the coast, on sections as nearly at right angles with the stream as practicable, the sections starting from some point well known in position. The temperatures were to be taken at distances diminishing as the changes of temperature were more rapid. So in regard to the depths, the observations were to be multiplied in the strata of rapidly varying temperatures near the surface. So in regard to position, when the cold water near the coast was rapidly exchanging for the warm water of the Gulf Stream, the sections diminishing in distance as the source of the warm water was approached.

The vessel's position was determined with reference to some prominent point, Sandy Hook, or Cape May, for example, the course run was perpendicular to the supposed axis of the stream, S.E., several positions were taken up in succession and at each the temperatures ascertained at the surface, at 5, 10, 15, 20, 30, 50, 100, 200, 300, 400, 600 fathoms, or depths found to apply more satisfactorily under the general rule, to the position and section. Having crossed the stream any position found to be desirable, could be assumed on returning, and the extreme position reached was verified by the return to the coast.

The summer season was selected for the standard observations for various reasons, but chiefly for two, namely, that the weather permitted more accurate work, and the phenomena were more likely to be those of equilibrium, when the surface water was more slowly changing its temperature. Our little vessels could not, without considerable danger, be exposed to the roughness of the wind and water in the Gulf Stream in winter, and when we attempted comparative winter observations, disappointment was often the result. The loss of one valuable officer and ten of his crew, and the extreme peril of another in autumnal explorations of the stream, has but too fully justified these precautions. The propriety of selecting the summer for making the observations was completely proved by the success in determining the laws of temperature.

These observations were but incidental to the hydrography of the coast, and hence were prosecuted only when means could be spared from other more pressing and regular parts of the work. It was only a favorable conjuncture with regard to officers, means, weather, adaptation of vessel, and the like, which gave results even when attempted. Too much credit cannot be assigned to those who háve succeeded in this laborious and perilous work, and their names have been kept in close connection with their results, whenever and wherever brought before the public, and they have been carefully preserved in the archives of the Survey. Charles H. Davis, George M. Bache, S. P. Lee, Richard Bache, John N. Maffitt, T. A. Craven, Otway H. Berryman, B. F. Sands and John Wilkinson make up the list of our successful observers in this field within the last sixteen years. Their names you will see attached to the sections run by them on the general chart of the Gulf Stream presented to you this evening.

The first was run in 1844, from Nantucket south and eastward, by Commander C. H. Davis, now the accomplished Superintendent of the Nautical Almanac, and the last in 1860 by Lieut. John Wilkinson, from the Tortugas, southeast to the coast of Cuba. The work still goes on perseveringly.

The number of sections run has been fourteen, the number of positions on these sections occupied 300, and the number of observations made for temperature 3600. The limits below which the stream and the adjacent waters have been explored for temperatures are from latitude 23° N., to 41° N., and from longitude 83° W. to 66½° W. from near Havana to near Cape Cod, and from the Tortugas to 9½° E. of Cape Henlopen. The distance along the axis of the Gulf Stream to the most northeastern point in the North Atlantic, measures nearly 1400 nautical miles.

III. Method of Discussion of the Results.

These have generally been discussed by diagrams, sometimes by analytical formulæ; the former method is generally best adapted to the character and degree of accuracy and circumstances of the observation; the diagrams finally adopted after trials were chiefly of three different kinds, one for the discussion of the change of temperature with depths, the two others for the change of temperature with position as well as depth. Of the first of these diagrams Nos. 1 and 2, Plate I, are specimens. The depths constitute the ordinates and the temperatures the abscissæ of a curve, showing the law of change of temperature with the depth. Upon the horizontal lines at the top of the paper the temperatures from ten degrees to ten degrees Fahr. are written and on the vertical line at the side, the depths. The separate observations being represented by dots; the curve is drawn with a free hand among them.

The next two classes of diagrams give the distribution of temperatures across the sections. In the first the temperature corresponding to the same depth; in the second the depths corresponding to the same temperatures. In this latter the figure of the bottom is shown when ascertained. In both classes the distances from the cape, or headland, city or inlet, which is the origin of the section is marked, and the several positions occupied for observing, so that the abscissæ of the curve are the distances from the point of beginning. In the first (see diagram No. 4, Plate I,) the temperatures are marked on the vertical lines at the left side of the diagrams, the ordinates of the curves thus corresponding to temperatures. In the second (see diagram No. 9, Plate I,) the depths are similarly written, the ordinates thus corresponding to depths. The notes or legend, show in the first case to what depths the curves correspond and in the second to what temperatures. The observations at each position being plotted according to its temperature or depth in the two classes of diagrams, the curve is drawn with a free hand among the points.

It should be observed that the discussion of each season's observations was in general made separately, and that the result of one, two or three seasons, grouped, were announced separately, leaving to the new observations to confirm, or refute, the conclusions drawn. It is a remarkable fact that with such difficulties in the way, in the character of the phenomena to be observed, in the diversity of seasons and of observers, the phenomena have always been readily deducible from the observations, and that the separate discussions have been confirmations, the following of the preceding; in short that the nature of the medium in which the work has been performed in its relations to heat, has more than compensated for other difficulties and that the results are more accordant than the elaborate ones obtained from the progress of temperature below the surface of the ground by the experienced and skillful observers who have made them. Few observations have been rejected in the whole series.

I need not notice special diagrams which will be explained when your attention is called to them.

When the character of the diagrams to be made had been definitely fixed, they were prepared under the direction of the chiefs of the parties, so that I was relieved of the personal labor of representing the results. In the subsequent general discussion I was greatly assisted by Prof. Pendleton, U. S. N. and by Prof. W. P. Trowbridge, Assistant U. S. Coast Survey, who has made a general review of the whole of the results preparatory to their publication in a volume of the Records and Results of the Coast Survey.

IV. Results.

1. *Type-curves of law of temperature with depths at the most characteristic positions.*—The two most characteristic positions are in the cold current between the land and the Gulf Stream and in the axis of the stream itself.

1. Diagram No. 1, Plate I, is a specimen of the type-curve in the cold current. The long tongue from the surface to about 50 fathoms in depth is the overflow of the warm water of the Gulf Stream, the temperature varying from 81° to about 55°. The

temperatures in the mass of water from 50 fathoms down to 500 fathoms are just such as would take place in a mass of water heated by conduction from the surface, the law is that of a logarithmic curve, in which the conducting power of sea water is the modulus of the system.

A comparison of many of these curves with the logarithmic form showed that it was applicable to them within the limits of the probable error of the observations. Taking the warm stratum from the Gulf of Mexico above and the cold polar stratum below, the mass of the water between is heated by conduction. The bottom of the sea has not been reached under the axis of the Gulf Stream, north of Cape Lookout on the North Carolina coast.

This form of curve was deduced in 1844 from the observations of Commander Charles H. Davis and was the first discovery made in connection with the then recently commenced systematic exploration of the Gulf Stream by the Coast Survey.

2. Nos. 2, 3, and 3 bis, Plate I, are specimens of the type-curve in the Gulf Stream, taken from the sections off Cape Henry, Cape Hatteras and Charleston, being characterized by the comparatively short beak or projection and the persistence of the higher temperature to great depths as 55° to 425, 450, 550 fathoms giving the peculiar shape to this curve between 50 and 500 fathoms.

II. Type-curves of distribution of Temperature across the Stream.

(*a.*) *Curves of temperature at the same depths.*—The sections made are the following, beginning the enumeration at the Gulf of Mexico: 1. Tortugas to Havana. 2. Sombrero Key to Salt Key. 3. Carysfort, L. H., to Cuba. 4. Cape Florida to Bemini. 5. Off Cape Cañaveral. 6. Off St. Augustine. 7. Off St. Simon's, Georgia. 8. Off Charleston. 9. Off Cape Fear. 10. Off Cape Hatteras. 11. Off Cape Henry. 12. Off Cape May. 13. Off Sandy Hook. 14. Off Cape Cod, being on the average one to each hundred miles along the axis of the stream. These are marked on the general chart, Plate III, the names of the explorers being stated in the column which gives the point of origin of each section.

The Sandy Hook curves, Nos. 4 and 5 Plate I, are among the best of the type-curves of temperature at the same depth, though among the earliest determined. The overflow of the Gulf Stream into the long space occupied by the cold current between it and the shore, mixing in a degree with the cold water, is well shown by the curves *a*, *b* and *c* at the surface, 5 and 10 fathoms, and the still greater admixture with the cold water at 20, 30 and 50 fathoms (*d*, *e*, *f*.) The whole space from the shore to 240 miles, is occupied, however, with comparatively cold water. Then is met the sudden rise to the Gulf Stream shown especially below 50 fathoms and termed so appropriately by Lieut. George M. Bache the "cold wall," that navigators have not hesitated to receive the term into use; next the hot water of the Gulf Stream, rising to a maximum of 82°, then falling to a minimum of 80°, rising to a second maximum of 81¼°, falling to a second minimum of 78° and rising from this toward a third maximum. With these results the curves at 5 and 10 fathoms and those at 20, 30, 50, 70, 100 and 150 fathoms agree and, with characteristic differences, those of 200, 300, 400 and 500 fathoms.

The cold wall at 20 fathoms shows a rise of 19° in 25 miles, three quarters of a degree to a mile, and at 200 fathoms of 16°, in the same distance; at the surface it is nearly 8° in 50 miles. The cold water between the Gulf Stream and the shore has two well marked maxima and two minima in it, of which one seems to correspond in position to the sudden deepening of the water 100 miles from Sandy Hook, as shown by the Coast Survey offshore chart between Gay Head and Cape Henlopen.

These results are more distinctly seen by grouping the curves into natural groups and taking the mean of their indications. Diagram No. 5 Plate I, gives the group of six curves from the surface to 30 fathoms, of four curves from 40 to 100 fathoms, both inclusive of 200, 300, and the single curve at 400.

Similar groups are shown on Diagram No. 6, Plate I, from Cape Henry, the cold wall, three maxima of temperature and three minima being very distinctly seen. The results of three different explorations of this section, by three different officers, in three different years, are shown upon the same diagram. The coincidence of result could hardly be better. The average of the whole of the observations is shown in No. 6 bis, Plate I.

The cold wall here gives a change of 22½° in 50 miles from the curves between 0 and 30 fathoms and 18° in 50 miles in the mean of 200, 300 and 400 fathoms.

The average of the three years comes out beautifully on Diagram No. 6 bis, Plate I. The Charleston curves are shown upon No. 7, Plate I. They are less regular than those just given, for reasons which will appear, when I come to speak of the second class of diagrams.

The conclusions deduced from the examination of all the sections between Cape Florida and Sandy Hook is, that the Gulf Stream is divided into alternate bands of hot, or warm and cool or cold water, the most distinct of which is that containing the axis of the Gulf Stream.

That between the stream and the coast there is a fall of temperature so sudden that it has been aptly called the cold wall, less distinct at the surface and where the overflow from the Gulf Stream passes furthest toward the shore, but still distinctly marked even at the surface.

Navigators have noticed these changes of temperature and have supposed themselves at each occurrence of warmer water to be in the hottest water of the stream and so have been greatly embarrassed and have deemed the phenomena and limits of the Gulf Stream to be very irregular.

The cold water between the Gulf Stream and the shore has also bands less regular than those beyond the axis of warmer and cooler water.

The intrusive cool water in the Gulf Stream on the Sandy Hook section was distinctly recognized in 1846 by Lieut. Geo. M. Bache, who from the facts observed, supposed it to represent a division of the warm water of the stream into two branches.

Passing through the Straits of Florida between the keys and reefs and the coast of Cuba we have after going beyond Cape Florida, a different type-curve. The cold wall is less distinctly marked and the rise of temperature is less marked. It rises however to an axis near the coast of Cuba. Throughout the length of the Strait there is but one maximum of temperature and the bands belonging to the Atlantic regimen do not occur in the straits. (See diagrams Nos. 3, 4, 5, 6, Plate II.) The cause of this change of regimen will be seen in presenting the other form of diagram.

(*b.*) *Curves of depths at the same temperature.*—I have selected curves from the southern portions of the work, partly because the bottom has been struck in the sections and the diagrams show its sections as well as those of the stream, and partly to show how fully the deductions in regard to the divisions of the stream, apply to these, as well as the more northern sections. The Charleston section of Lieut. Maffitt is given on diagram No. 9, Plate I. The surface curve, notwithstanding the disturbance by a storm, shows the cold wall, (see also No. 7) the axis and two other maxima, the corresponding minima, a maximum within the cold current which is not therefore, as has been supposed, cut off at Hatteras, the curve of 72° reaching to the coast and 77° nearly reaching it. The Cape Florida diagrams (Nos. 3 and 7, Plate II.) give two maxima with indications of a third and the corresponding minima. The cold wall cannot be recognized upon it, probably for the want of one or two, more positions.

The form of the bottom delineated on these two sections, namely the Charleston and Cape Florida sections, is remarkable and applies to the sections between them as far as explored. First is a gentle slope, then a sudden descent, a second steep pitch to a considerable depth, a range of hills, a valley and a second range.

The correspondence of these features with the bands of temperature is plainly marked. The cold water lies in the valleys and passing along the bottom rises upon the tops of the hills. The discovery of this range of hills was made at nearly the same time by Lieut. Maffitt on the Charleston section and by Lieut. Craven on the St. Simon's section. Diagram No. 9, Plate I, shows this connection in a very striking manner as does also No.7, Plate II, and the figure of the bottom of the straits of Florida, shows why there are no bands formed prior to passing Cape Florida, in other words, why the regimen of the stream is different in the straits and in the Atlantic. In the straits we see (No. 9, Plate II) that after leaving the United States shore and the comparatively flat surface extending to the reefs, there is a rapid descent toward the Cuban side of the strait, the axis of the Gulf Stream being found in the deep hollow of that side of the strait.

These results, with a more elaborate discussion of them, were presented at the last meeting of the Association. It would seem from the configuration of the bottom, that the cold stream at the bottom of the straits of Florida divides, one portion passing to the north and west into the Gulf of Mexico and the other around the western end of the Island of Cuba. That the polar stream still occupies the bottom of the strait is shown by temperature of 35° Fahr. being reached at 600 fathoms from the surface off Havana.

Do these bands correspond throughout their length to the form of the bottom of the sea? This is not yet made out, many as have been the attempts to reach the considerable depths off the more northern sections. Three officers have attempted to sound out the Cape Cod section, but the cold wall is all that has been reached thus far. The range of hills nearest to the coast, has been traced from the coast of Georgia by Commander Sands to off Cape Lookout.

III. The Cold Wall.

The cold wall extends with varying dimensions and changes of its peculiar features, all along the coast where the stream has been examined. A diagram showing the features of the cold wall on the various Atlantic sections and those of the straits of Florida is given in No. 10, Plate I. Table No. 1 shows the distance of the cold wall from the coast and the dimensions of the Atlantic bands of the Gulf Stream.

The table shows that at Cape Florida and Cape Hatteras the cold wall is nearest to the coast. The distance of the axis of the stream from the coast will be found by adding half the numbers in the second column to those in the first column. It is obvious from these numbers, when taken in connection with the longitudes of the points where the sections originate, that the earth's motion is not the sole determining cause of the direction of the axis of the stream, a result which a more elaborate investigation of the movements from parallel to parallel confirms. In the portions of its course between Cape Florida and Mosquito inlet ($3\frac{1}{4}$° of latitude) the curve is actually slightly to the westward.

TABLE 1.—*Distance of the cold wall from the shore, and widths of the several bands of cold and warm water in the Gulf Stream, measured on the lines of the Sections.*

Names of Sections.	Distance of cold wall from shore in miles.	Width of 1st maximum or warm band.	Width of 2d minimum or cold band.	Width of 2d maximum.	Width of Gulf Stream, proper.	Width of 3d minimum or cold band.	Width of 3d maximum or warm band.	Width of 4th minimum or cold band.
Sandy Hook........	240	60	30	37	127	60	50	Indef.
Cape May..........	125	55	30	40	125	70	65	70
Cape Henry........	95	45	32	47	124	80	60	50
Cape Hatteras......	30	47	25	45	117	37	75	70
Cape Fear..........	60	30	20	37	87	30	60	25
Charleston.........	62	25	15	30	67	26	35	—
St. Simons.........	87	25	13	20	58	25	25	—
St. Augustine........	70	20	13	12	47	22	20	—
Cape Cañaveral.....	35	20	—	—	35	14	12	—
Cape Florida.......	10	25	—	—	25	5	—	—

Note.—The width of the bands beyond the 2d maximum, and north of Cape Hatteras are somewhat indefinite.

The table shows a width in the Gulf Stream proper along the Atlantic coast of from 25 miles off Cape Florida to 127 miles off Sandy Hook. The warm water at say fifteen fathoms, is from 30 to 150 miles in width. The stream widens each way from Cape Florida. These several divisions of the Atlantic stream lose a portion of their distinctness as we pass northward and eastward, the stream widening.

IV. LIMIT OF ACCURACY OF THE DETERMINATIONS.

There are two modes by which the limits of accuracy of these results may be tested, by one of which their permanency is also tried. In this latter mode the sections are run over in different years, or in the same year by different officers, so as to connect the observations of one year with those of the next, or of one officer with that of another. Table No. 2 shows that the relative results are reproduced from year to year with less variability than those of the mean temperature of the section; and hence the permanency of the bands and the possibility of observing them with the requisite precision must be admitted. On the Cape Henry section which was explored three times, the position of the cold wall and of the axis of the stream were reproduced within $5\frac{1}{2}$ miles and those of the succeeding points of maximum and minimum temperatures within $7\frac{1}{2}$ miles. As the positions at sea are liable to an uncertainty of some three to five miles it must be admitted that the permanency of the bands and the accuracy of the observations of them are fully proved.

The Cape Henry section was run over by Lieuts. G. M. Bache, S. P. Lee, and Richard Bache, the Hatteras section by Lieuts. Richard Bache and J. N. Maffit, and the Charleston section by Lieuts. J. N. Maffit and T. A. Craven.

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TABLE 2.—*Table showing the probable uncertainty in the determination of maximum and minimum points, by running the same section over in different years by different observers.*

CAPE HENRY SECTION.

Dates and names of observers.	Mean distances from the shore in miles from the curves representing the groups.						
	Cold wall or 1st min	Axis or 1st max.	Second min.	Second max	Third min.	Third max	Fourth min.
Lt. G. M. Bache, 1846	93	135	187	218	260	320	369
" S. P. Lee, 1847	91	146	185	215	291	337	338
" R. Bache, 1848	97	146	180	197	287	328	370
Means for three years.	84	142	184	210	279	328	370
Probable error for each year.	5·85	4·27	2·42	7·62	11·51	5·71	7·18
CAPE HATTERAS SECTION.							
Lt. R. Bache, 1848	—	90	134	162	214	286	355
" J. M. Maffit, 1853	—	75	125	157	211	256	322
Means for two years	—	82	129	159	212	266	338
Probable error for each year	—	6·4	4·3	2·4	1·5	15	16
Means for both sections	5·85	5·3	3·4	5·0	6·4	1·04	1·16

Average uncertainty of maxima and minima, 6·9 miles.
" " cold wall and axis, 5·5 "
" " all the other points, 7·4 "

The other mode of testing the result is by the comparison of the remarkable points in the different sections, each one belonging to a different position and therefore being entirely independent of the other in its determination. It is established as a general law that this cold wall and axis of the hottest water change their position from the surface to the depth of six hundred fathoms slowly and by an ascertained progression, and that the succeeding maximum and minimum points are at the same distance from the shore, nearly, at different depths, or in a vertical line at all the different depths. The positions of these points as shown by the observations at different depths become thus the test of the permanency of their positions and of the accuracy with which they have been ascertained. Table 3 gives the probable error of the mean of the determinations of each point including the cold wall minimum, the axis maximum, and the successive minima and maxima to the fourth minimum inclusive. These results show that the cold wall minimum is ascertained, on the average, within 0·83 mile, the axis maximum within two miles and a half, the second minimum within two miles and a half, the second maximum and third minimum and third maximum, within four miles, and the fourth maximum within eight and a half miles, all being satisfactory except the last, which of course is in reality loosely defined. The Hatteras result for the axis of the stream, makes the probable error considerably larger than it would otherwise be, probably from the fact that the proximity of the bottom of the sea, makes the result less permanent than in the other cases. Without this result the mean probable error would be 1·1 mile.

TABLE 3.—*Recapitulation, showing the value of the probable error of determination of the bands for each section and the average of the whole.*

Sections.	1st min.	1st max	2d min.	2d max.	3d min	3d max	4th min.
	Probable errors.						
Sandy Hook		·75		3·94	7·99		
Cape May	·82	1·25	2·54	1·57		4·03	4·87
Cape Henry, 3 years	·84	·61	·55	1·70	1·06	·94	3·42
Cape Hatteras, 2 years		6·77	6·36	9·31	5·69	6·23	
Cape Fear		1·25			2·98	3·49	13·37
Charleston	1·25	1·57	·72	2·09	2·40	·82	
St. Simons		·74	1·27	·41			
St. Augustine	·52	·51	·44	·44	·55		
Cape Cañaveral	·95	1·69	·39				
Mean probable error	·83	2·49	2·49	4·00	4·01	3·71	8·45

While these results are so permanent, the mean temperatures of the sections change considerably from year to year. The average temperature between the surface and 400 fathoms beyond, or outside of the cold wall on the Sandy Hook section in 1846, was as high as that on the Cape Henry section in 1848, and that on the Cape Fear section in 1853, within a degree of that of the St. Augustine section in 1853, while the Cape Hatteras section in 1848 and in 1853, differed two degrees in mean temperatures. Again the temperatures from the surface to 30 fathoms just below the axis of the stream in the Sandy Hook section in August 1846 was either as high or higher than those on the Cañaveral section in June 1853. In general the Cape May section in 1846 and the mean of the Cape Henry section of 1846, 1847 and 1848 are warmer at the same depths than the sections south of it were in 1848 and 1853.

These results show that there are great changes in temperature from year to year, and probably from season to season. Some progress has been made in connecting these results in a general way with the changes of weather in the Gulf of Mexico.

The depths at which the results are easily determined and where they are characteristic and as permanent as the phenomena permit is thirty fathoms.

V. FIGURE OF THE BOTTOM OF THE SEA, BELOW THE GULF STREAM.

We have seen that in cross sections there is a great resemblance in the bottom of the sea off our coast to the region of land more removed from the coast-line in the interior. The top of the first range of hills, (see Diagram No. 9, Plate I,) is 1500 feet above the valley to the eastward of it, distant 12 miles; and the top of the second range 600 feet above the same valley, distant 15 miles. The first slope is 125 feet, and the second is 40 feet,

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to the mile. The bottom of the sea from the Tortugas section to that of Cape Florida, rises from 800 to 325 fathoms, and from the same point descends, in passing northward and eastward. The Cape Florida section showed that there then was present a ridge of comparatively cold water since the division into bands should apply along the stream as well as in the direction of its cross sections. The temperature of 40° is in fact reached on that section at 300 fathoms, and, as well as can be judged from the results in the separate sections there are divisions of this sort. The diagram No. 2, Plate II, shows where the curves of 50° and 45° are found upon the different sections and indicates a rise on the Charleston section and a sharp descent from Charleston to Cape Fear.

VII. General features of the Gulf Stream.

Upon the general diagram now presented to the members, (Plate III,) the general features of the Gulf Stream are represented from the Tortugas to the Cape Cod Section. Passing along the Cuban coast the temperature in June was found to be about 84° or 8° above the mean temperature of Key West, as given by the Surgeon General's report. The current here is feeble, but sufficient to cause it to be sought by sailing vessels making to windward and even by steamers. Issuing from the straits of Bemini, the stream is turned northward by the land which confines and directs its course. Its effective velocity is not derived from difference of temperature, as the observations abundantly show, the greatest relative differences being in fact crosswise of the stream. The direction is here a little west of north and the velocity is from 3 to 5 miles per hour. The temperature bands now begin. The bottom of the sea which was one slope and counter slope, across the Florida Straits, is here corrugated; the depth instead of being unfathomable, as has heretofore been supposed, is but 325 fathoms, in which depth the two currents, from the poles near the bottom and from the Gulf at the top, must pass each other. While the surface water is above 80° that near the bottom is as low as 40°.

The stream just north of Mosquito inlet begins to bend to the eastward of north, and off St. Augustine has a decided set to the eastward. While flowing thus onward the warm water seeks the sides of the channel overflowing towards the coast of Florida, and towards the Bahamas, but not as rapidly as it moves on north. Between St. Augustine and Cape Hatteras the set of the stream and the trend of the coast differ but little, making 5 degrees of easting in 5 degrees of northing. At Hatteras it curves to the northward and then runs easterly, making about 3 degrees of northing in 3 degrees of easting. In the latitude of Cape Charles it turns quite to the eastward having a velocity of between one and one mile and a half the hour.

That this curve follows the general sweep of the coast under water, appears most probable, the coast line, the curve of 100 fathoms and the ranges of hills discovered by Lieuts. Maffitt and Craven all seem to indicate it. That the direction of the stream is given in a general way by the configuration of the bottom of the sea, is hardly possible to doubt, while admitting that it receives modification from other, and perhaps more general, causes. The after progress of this mighty stream, and of its branches if it does divide, remains yet to be traced and so also its heading in the Gulf of Mexico.

I forbear to mingle doubtful speculation upon causes, with the inductions in regard to temperatures, which it has been the object of these observations to supply and of this lecture to bring to your notice.